CFD Support For STS-107 Ascent Investigation

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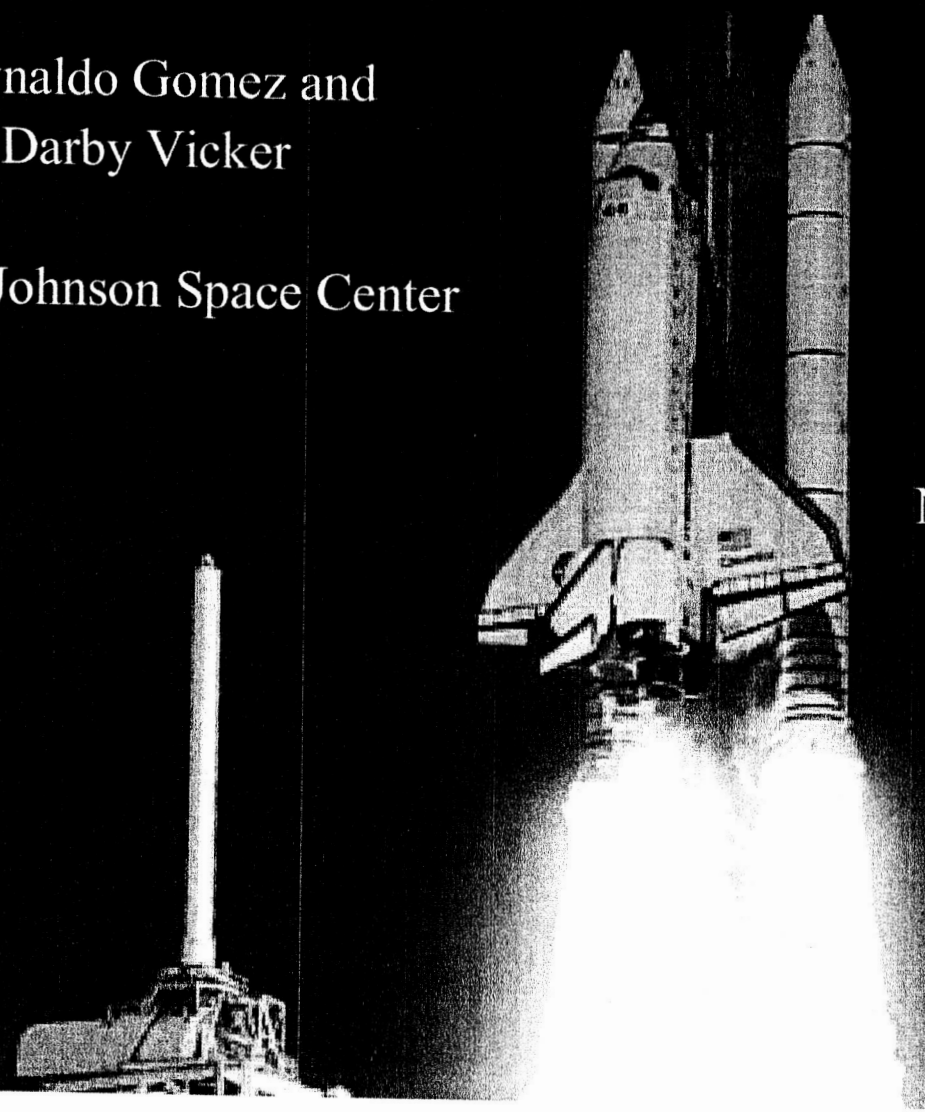

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Outline

- Introduction: Motivation and Goals
- Background
- Approach
  - Overflow steady-state computations
  - Cart3D unsteady 6-DOF debris
  - Overflow-D unsteady 6-DOF debris
- Computed results
  - Steady loads
  - Unsteady debris trajectories
- Findings reported to the CAIB
- On-going return-to-flight CFD efforts

Introduction

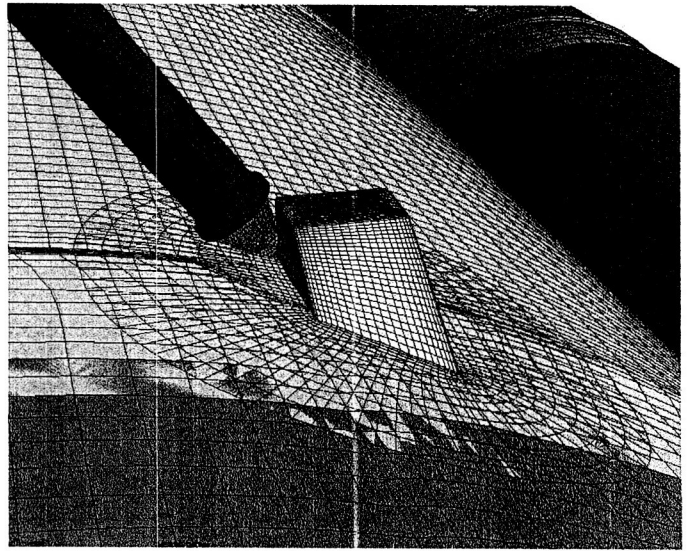
- Motivation:
  - Investigate ascent of STS-107 and foam-debris impact
  - Contribute to understanding of the STS-107 accident using CFD tools
- Goals:
  - Quantify loads on foam bipod ramp during ascent
  - Provide steady-state flow-fields to debris-transport simulations
  - Simulate flight of foam debris using unsteady 6-degree-of-freedom calculations
  - Provide estimates of foam mass, velocity, and impact angle which correlate with video and film evidence

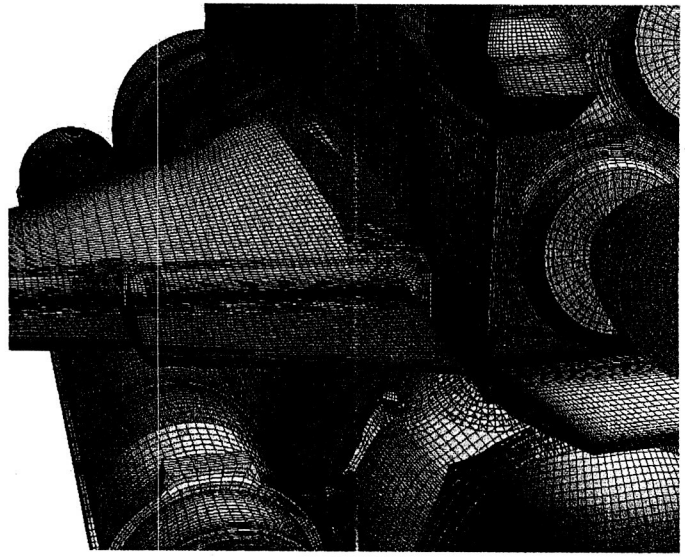
Background: SSLV and Overflow

- Overflow originally developed to study Space Shuttle Launch Vehicle ascent flow problems starting over 10 years ago
- 1993 Capability:
  - 16 million grid points
  - Approximately 1 week/solution
  - 2 weeks to change control-surface settings

Background: SSLV and Overflow

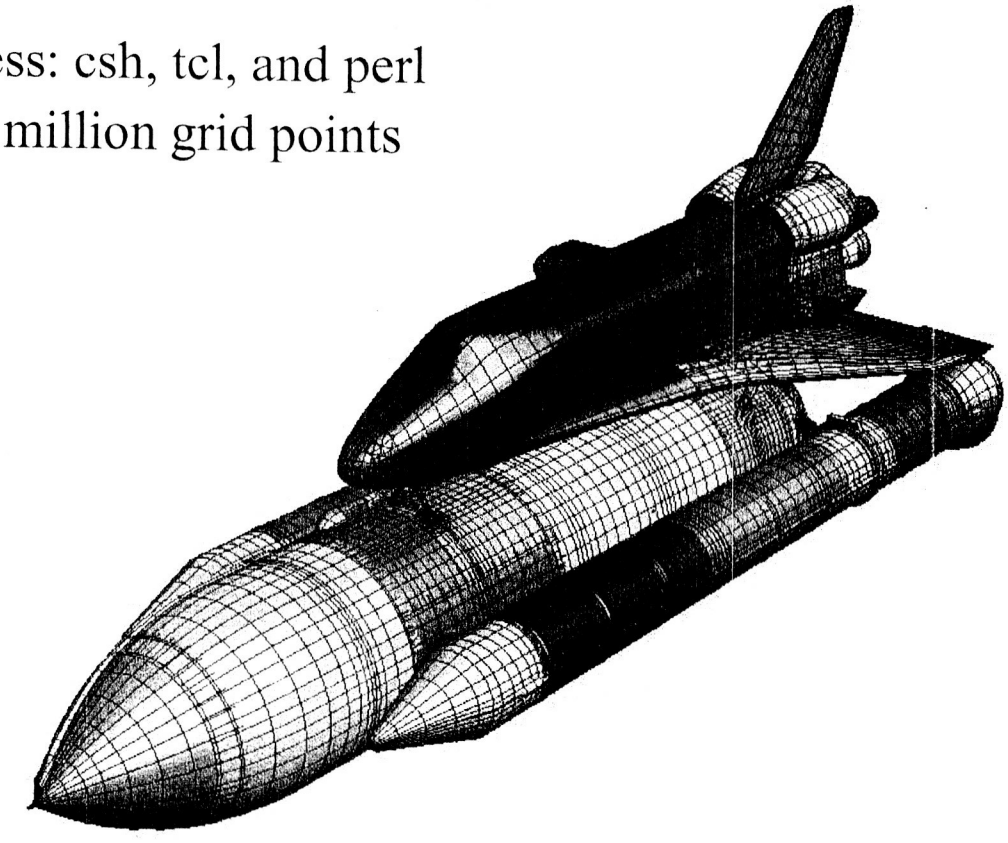
- Recent upgrades to fidelity of geometry and automation in progress when Columbia was lost
- Completed upgrades and began computing flowfields within first few weeks of the investigation





Overset Grid Generation

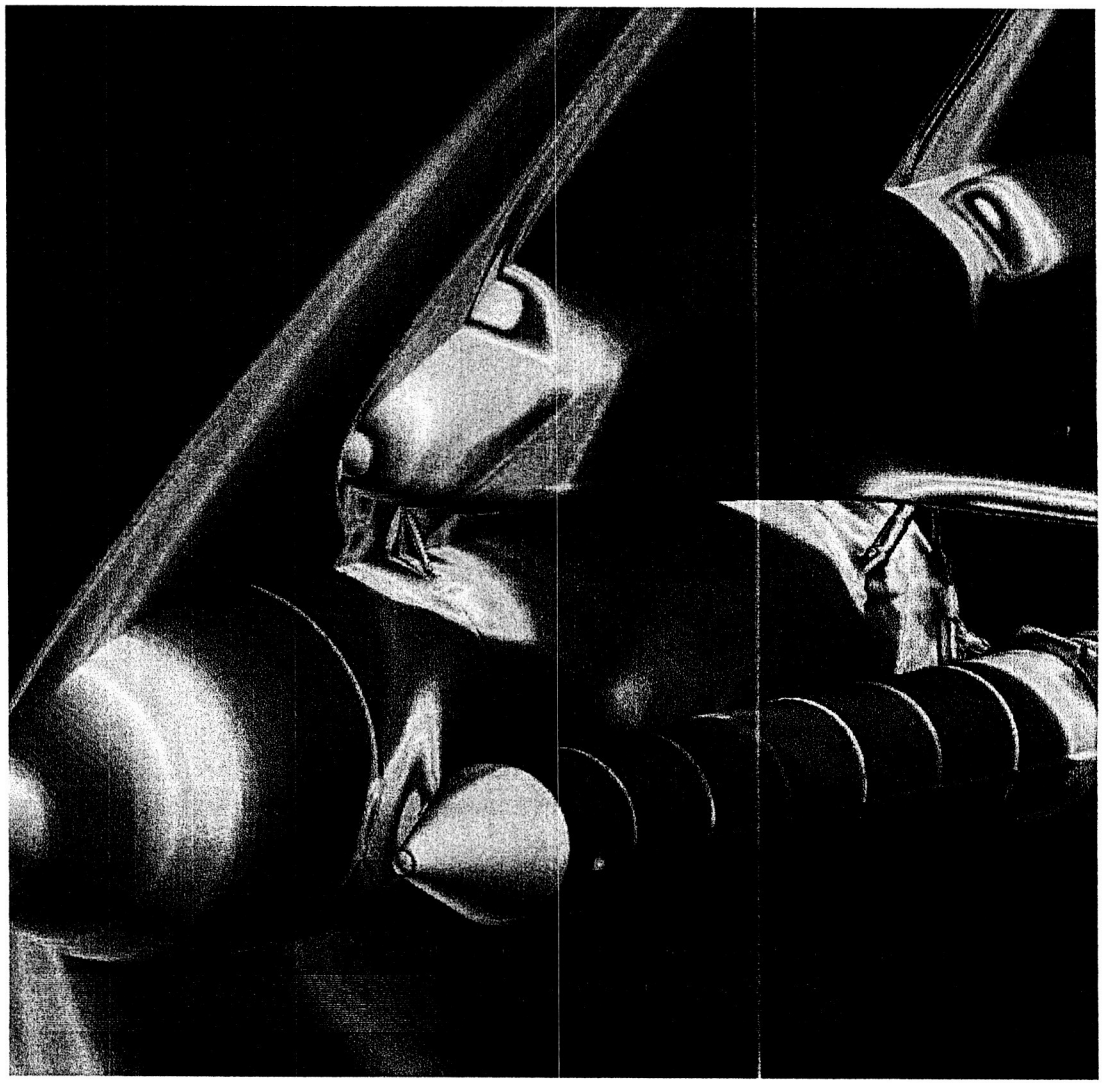
- Rapidly generate grid systems for different control-surface deflections, and different combinations of components
- Overset grid generation utilizes Chimera Grid Tools and Pegasus5 software
- Scripted process: csh, tcl, and perl
- 167 zones, 24 million grid points



Steady-State Overflow Solution

Mach = 2.46
Alpha = -2.08
Beta = -0.09
Re/ft = 1.46 million

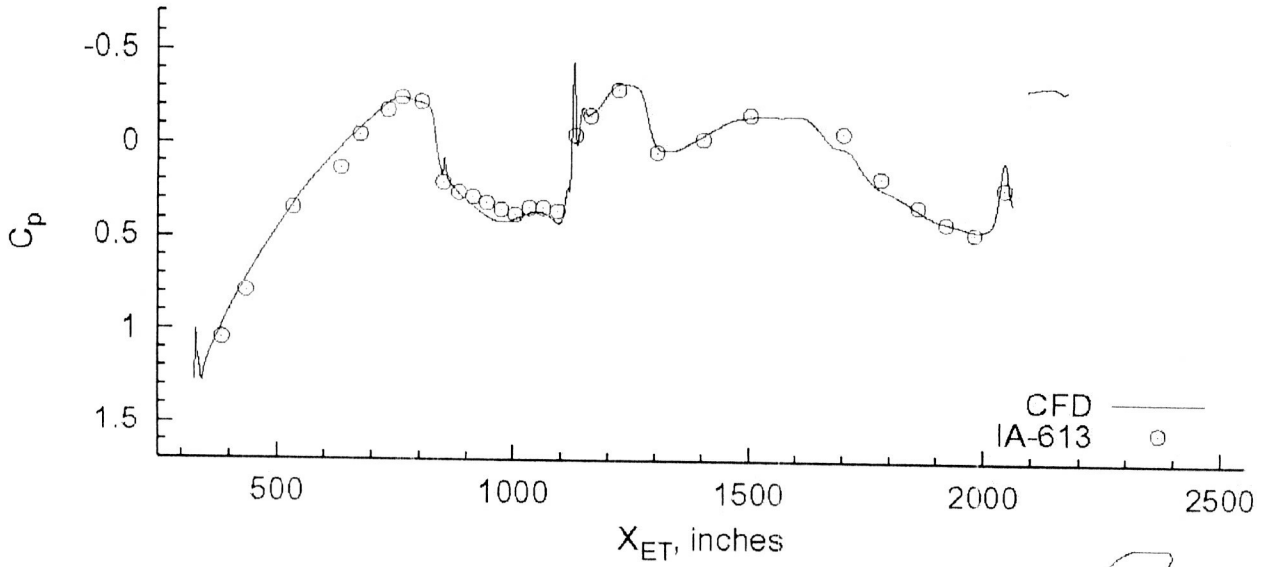
MET = 81.7 sec
Altitude = 65,820 ft
Density = 7% of sea level

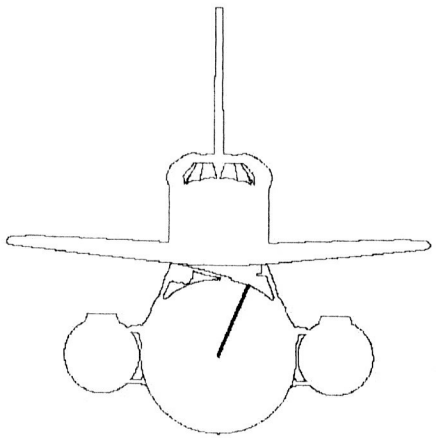


Wind Tunnel Test (IA-613) Comparisons - External Tank - Phi = 157.5°

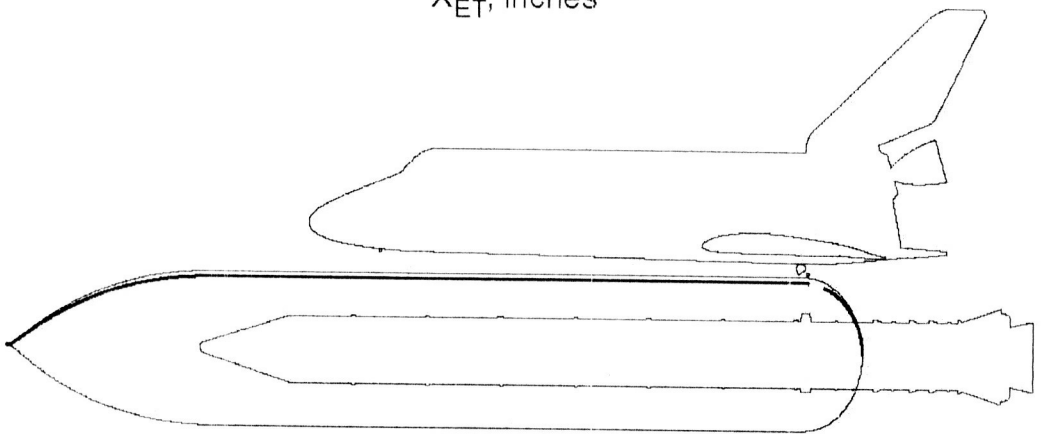
CFD conditions: M_∞ = 1.25, α = -3.95°, β = 0.00°, Reynolds # (million/foot) = 2.50, IB elevon = 10.00°, OB elevon = 5.00°

WTT conditions: M_∞ = 1.25, α = -3.95°, β = 0.00°, Reynolds # (million/foot) = 2.50, IB elevon = 10.00°, OB elevon = 5.00°





Front view looking aft



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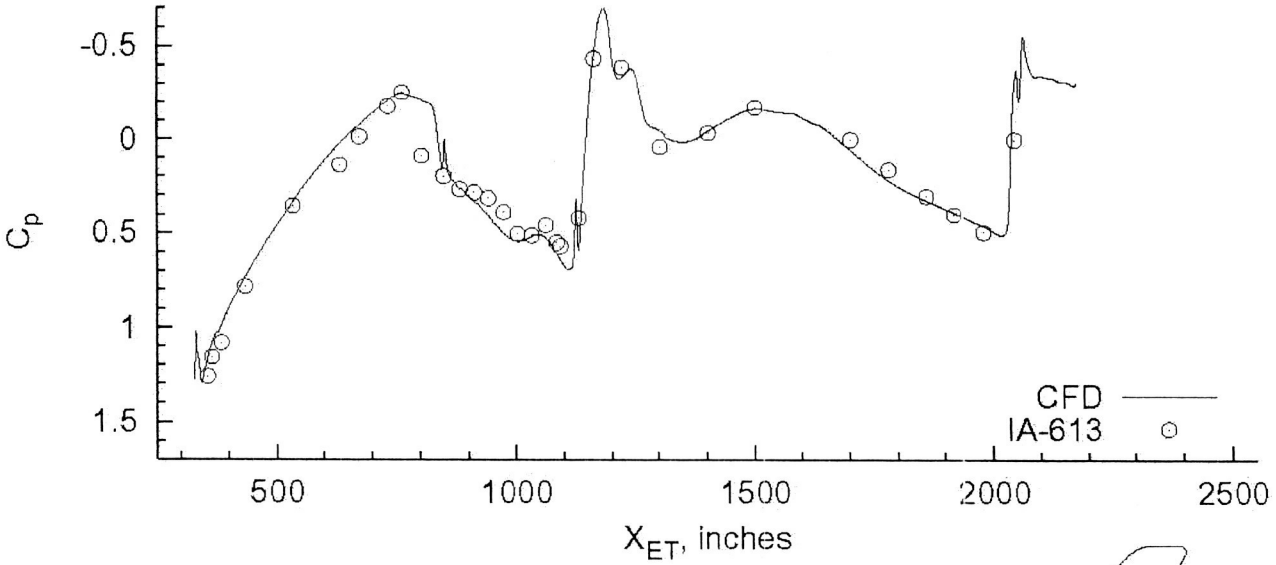
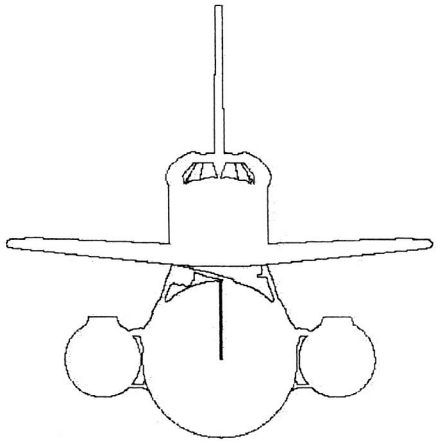
Wind Tunnel Test (IA-613) Comparisons - External Tank - Phi = 180°

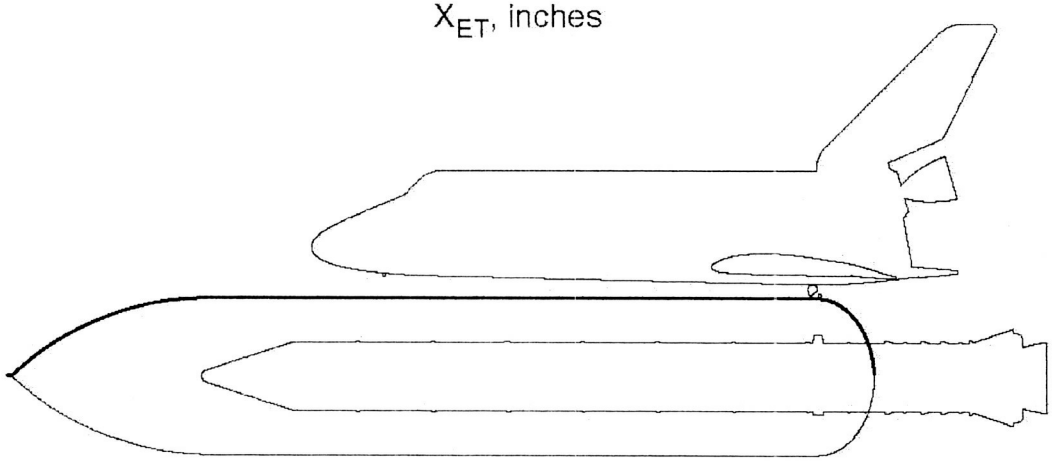
CFD conditions: M_∞ = 1.25, α = -3.95°, β = 0.00°, Reynolds # (million/foot) = 2.50, IB elevon = 10.00°, OB elevon = 5.00°

WTT conditions: M_∞ = 1.25, α = -3.95°, β = 0.00°, Reynolds # (million/foot) = 2.50, IB elevon = 10.00°, OB elevon = 5.00°





Front view looking aft



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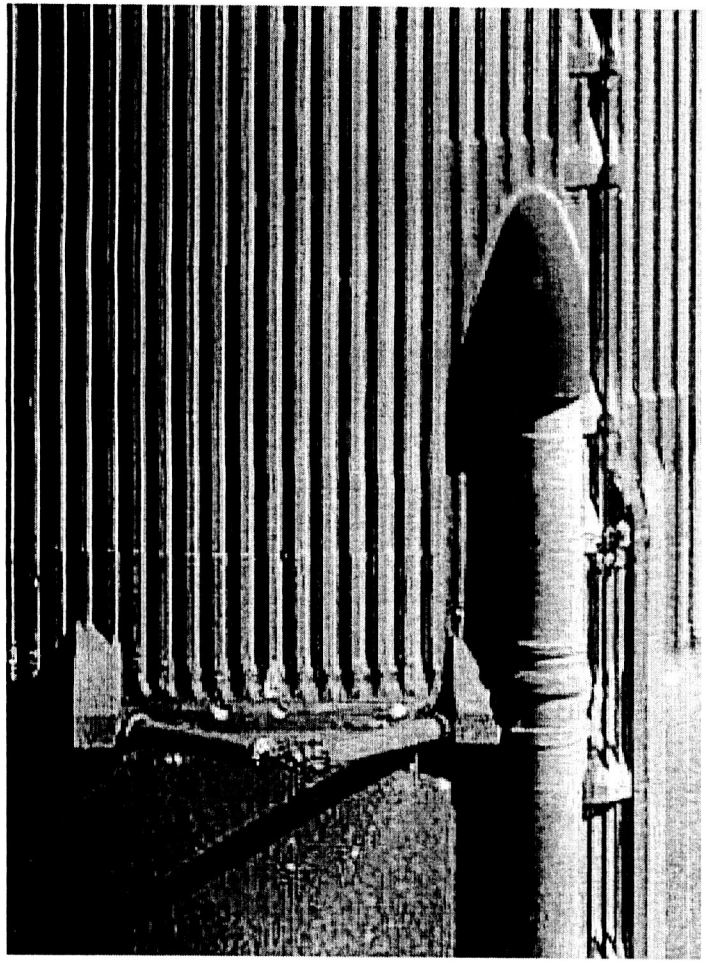
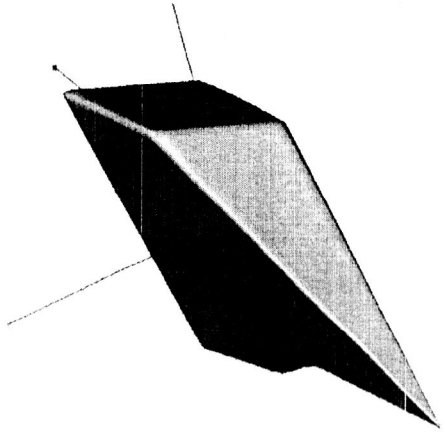
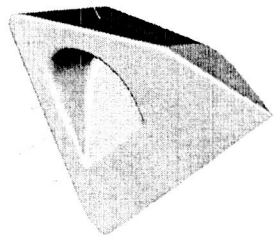
Bipod Ramp Debris



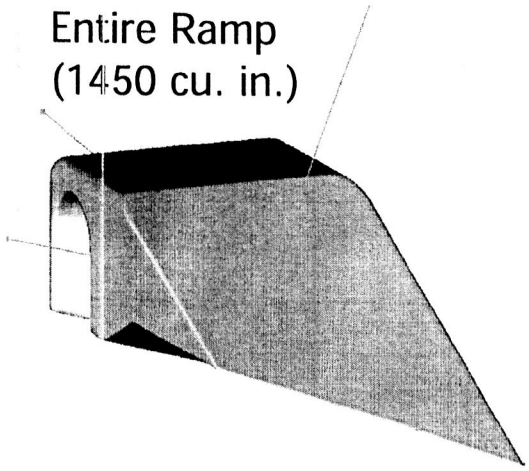
Preliminary STS-112
debris (420 cu. in.)



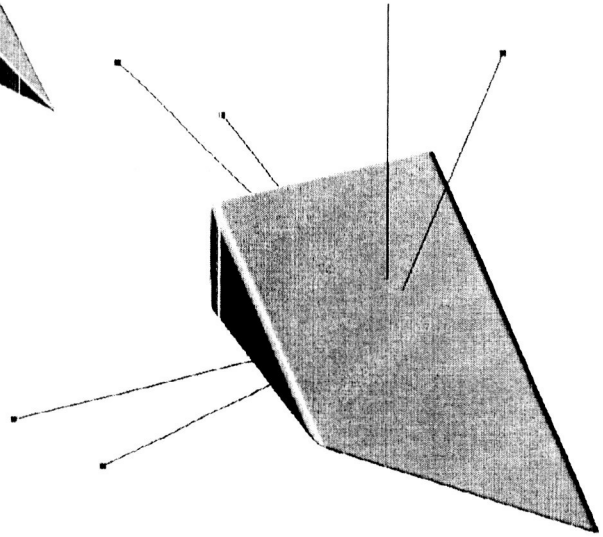
Refined STS-112
debris (167 cu. in.)



Entire Ramp
(1450 cu. in.)

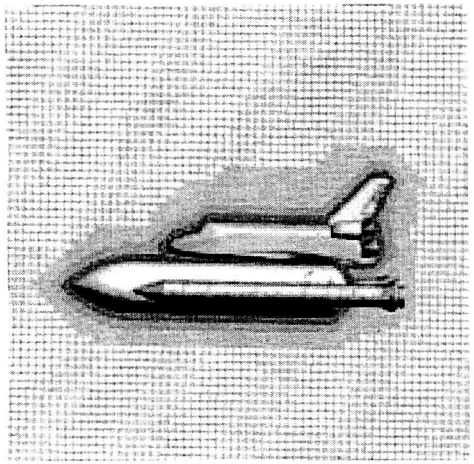


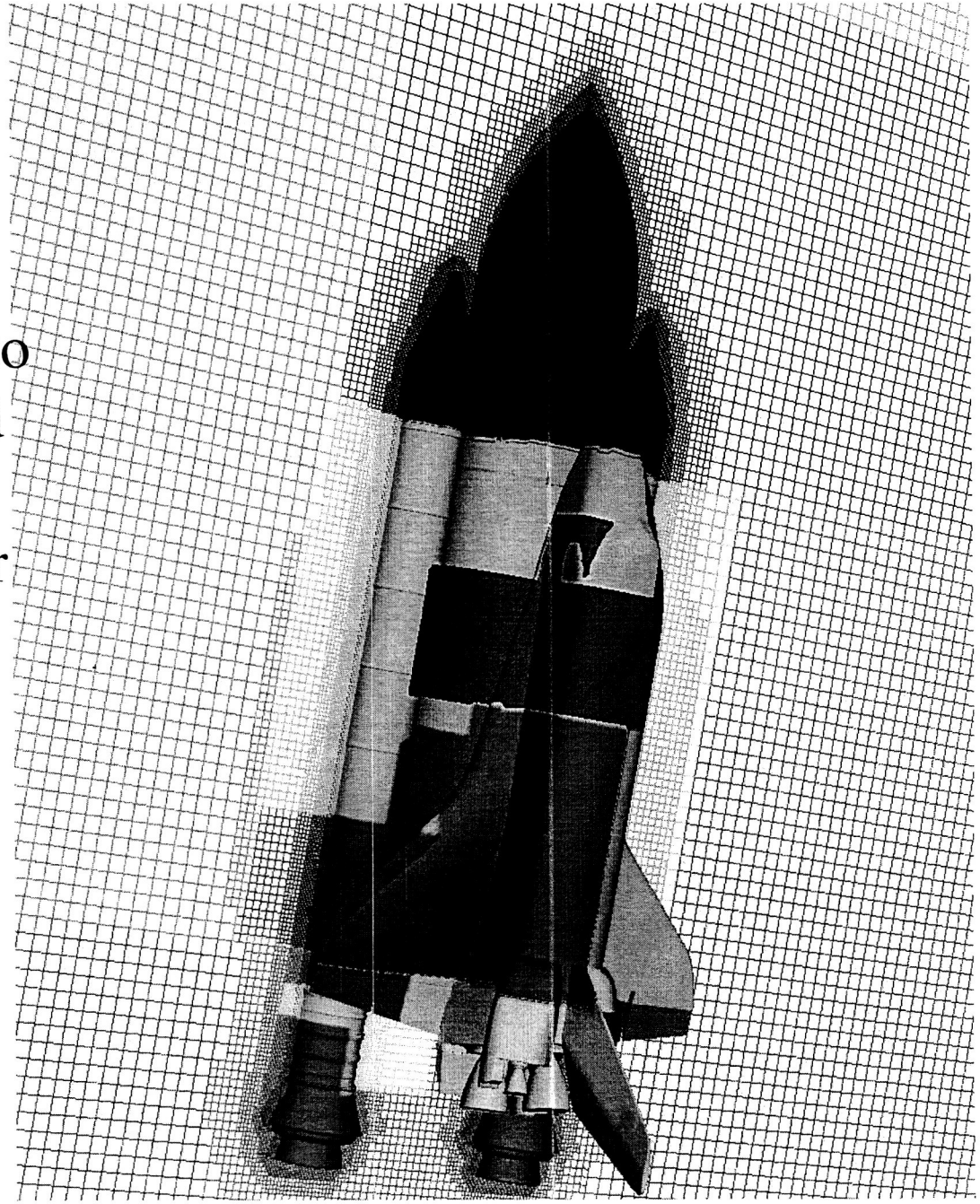
"Largest Possible" STS-107
debris (855 cu. in.)



Mesh Generation - *Cart3D*

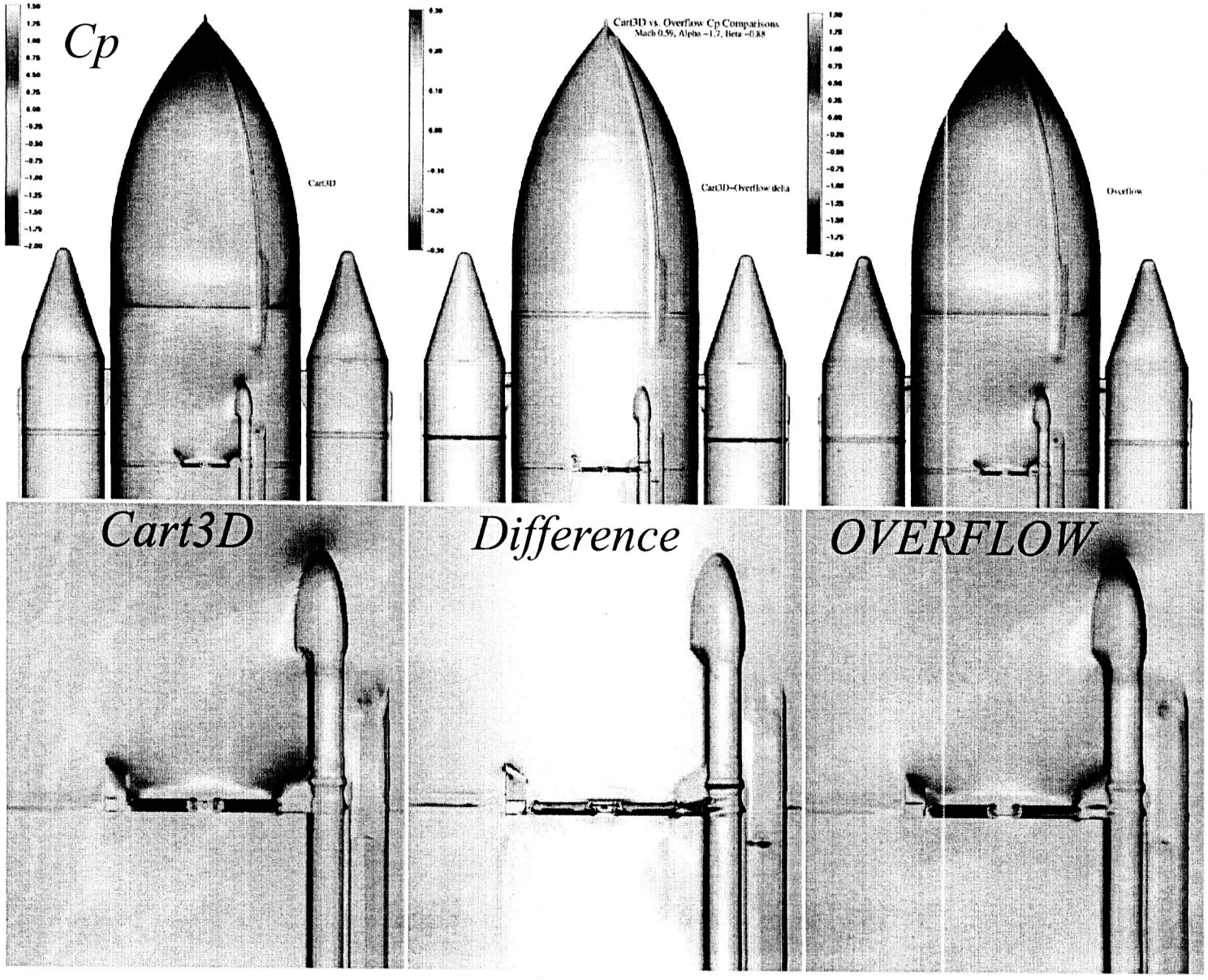
- Work from existing surface meshes and CAD geometry from JSC
- Highly automated, easy to incorporate new/updated geometry.
- Partitioned on-the-fly for any number of CPUs



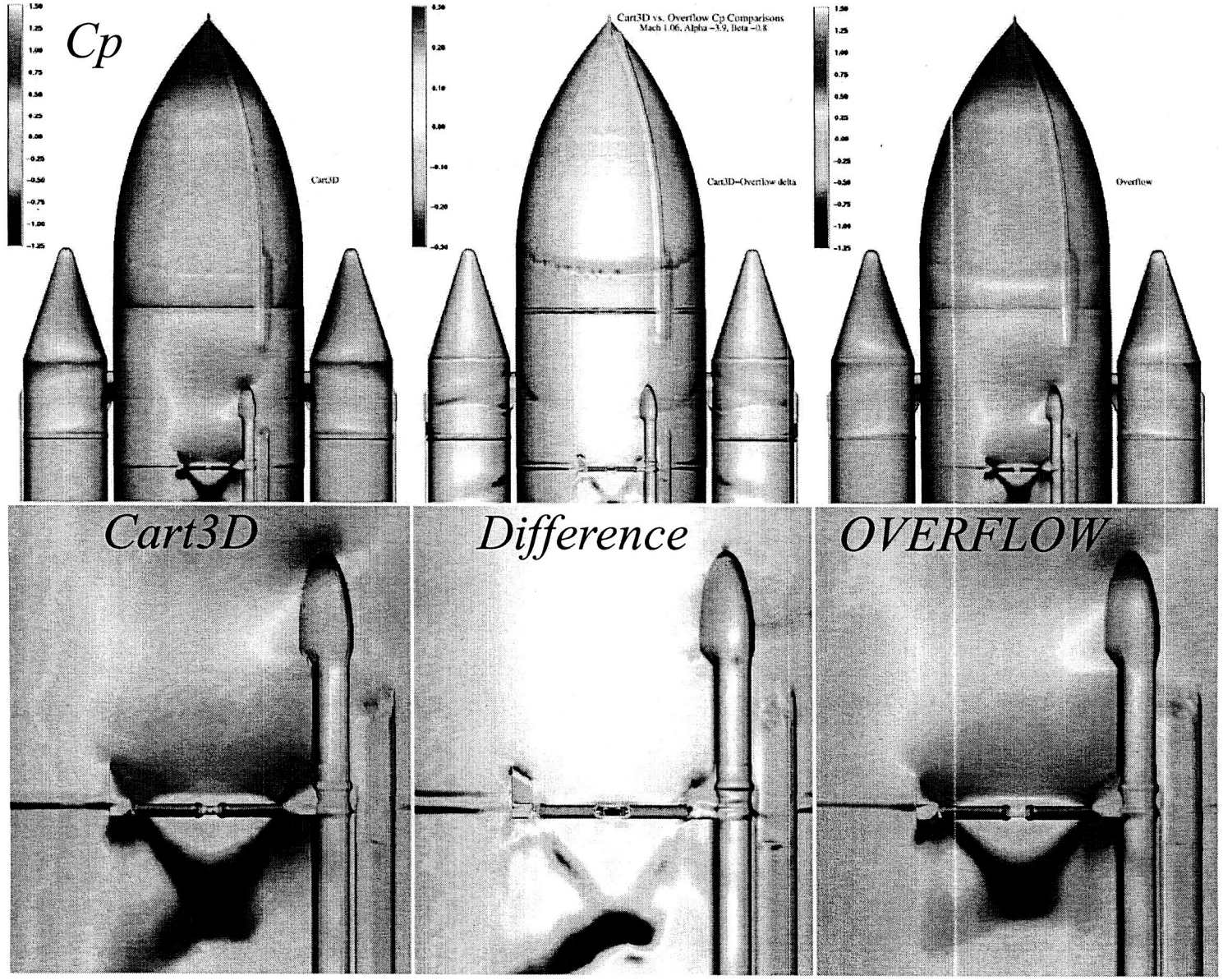


Strengths and Weaknesses of Techniques

$M = 0.6$ @ ~8,300ft

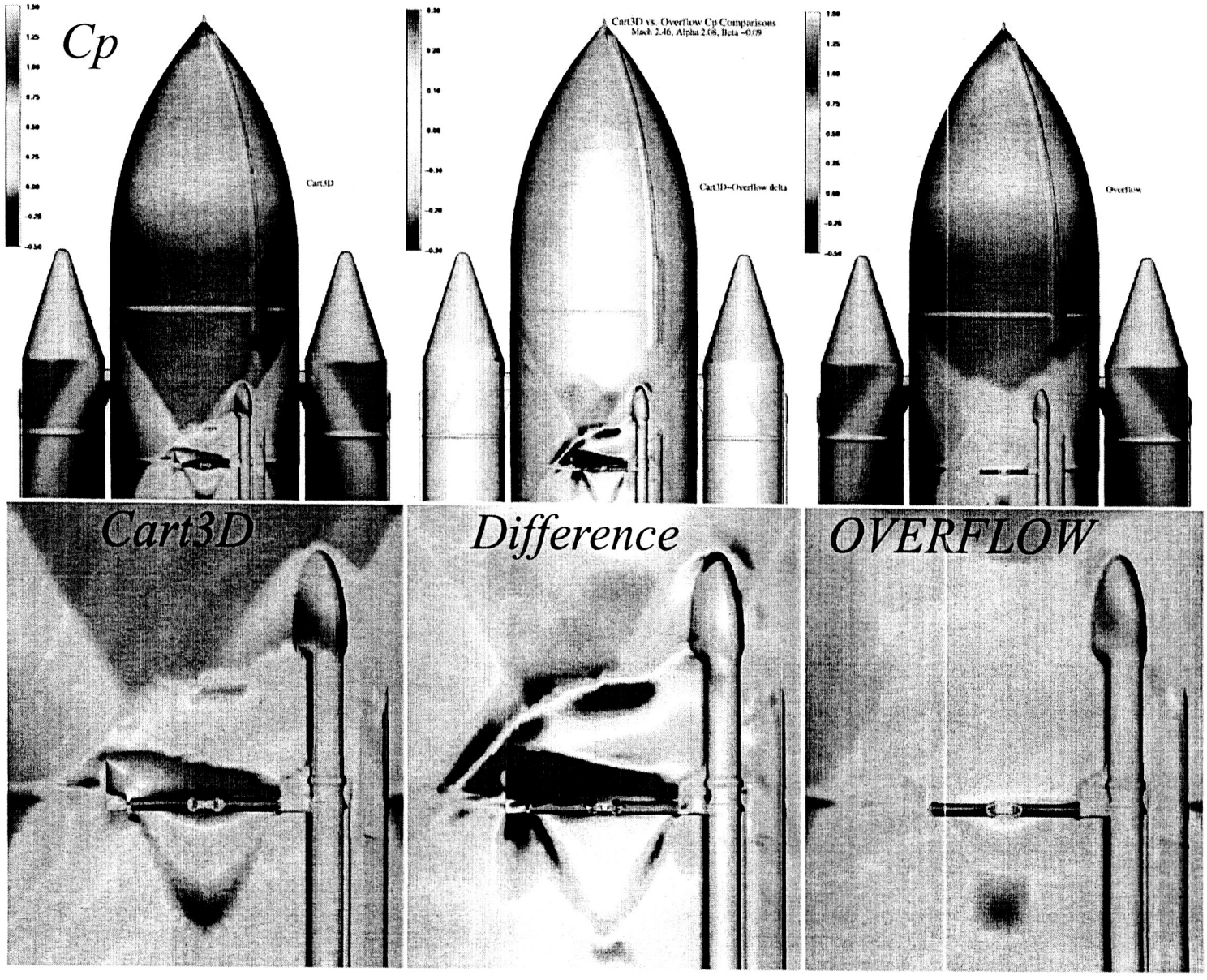


Strengths and Weaknesses of Techniques
$M = 1.06$ @ ~23,500ft



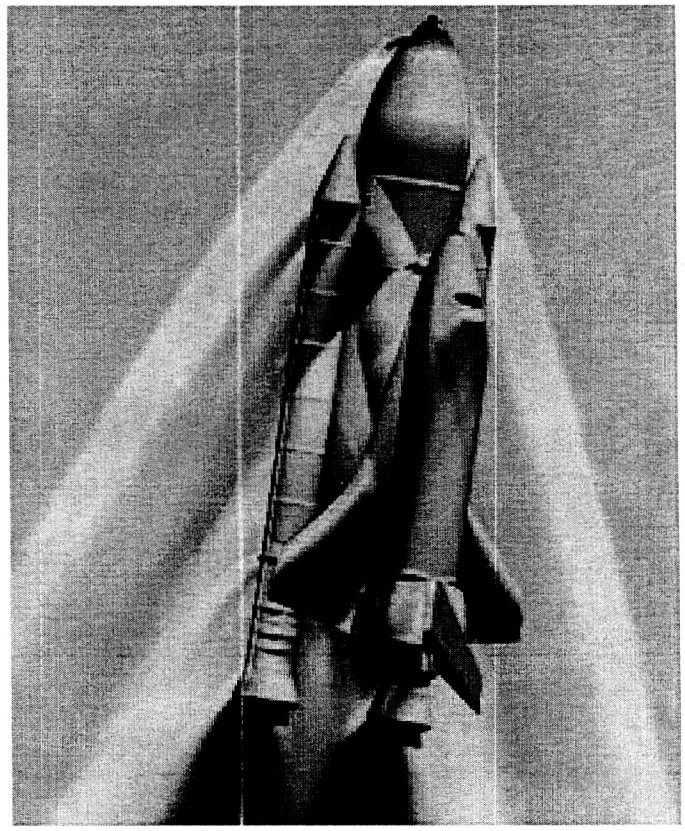
Strengths and Weaknesses of Techniques

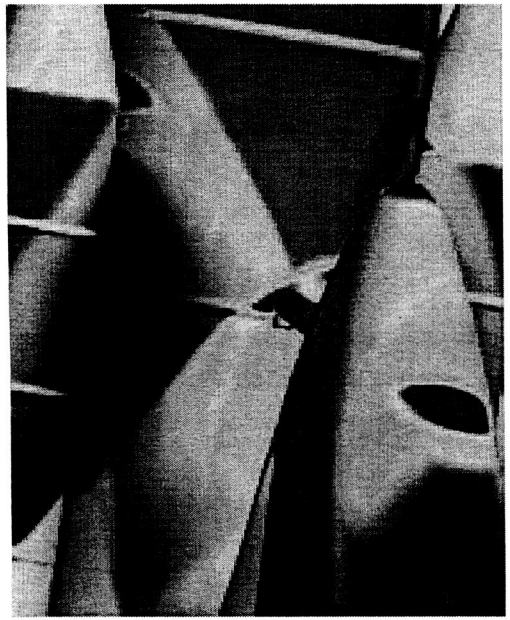
$M = 2.46$ @ ~65,600ft



Strengths and Weaknesses of Techniques

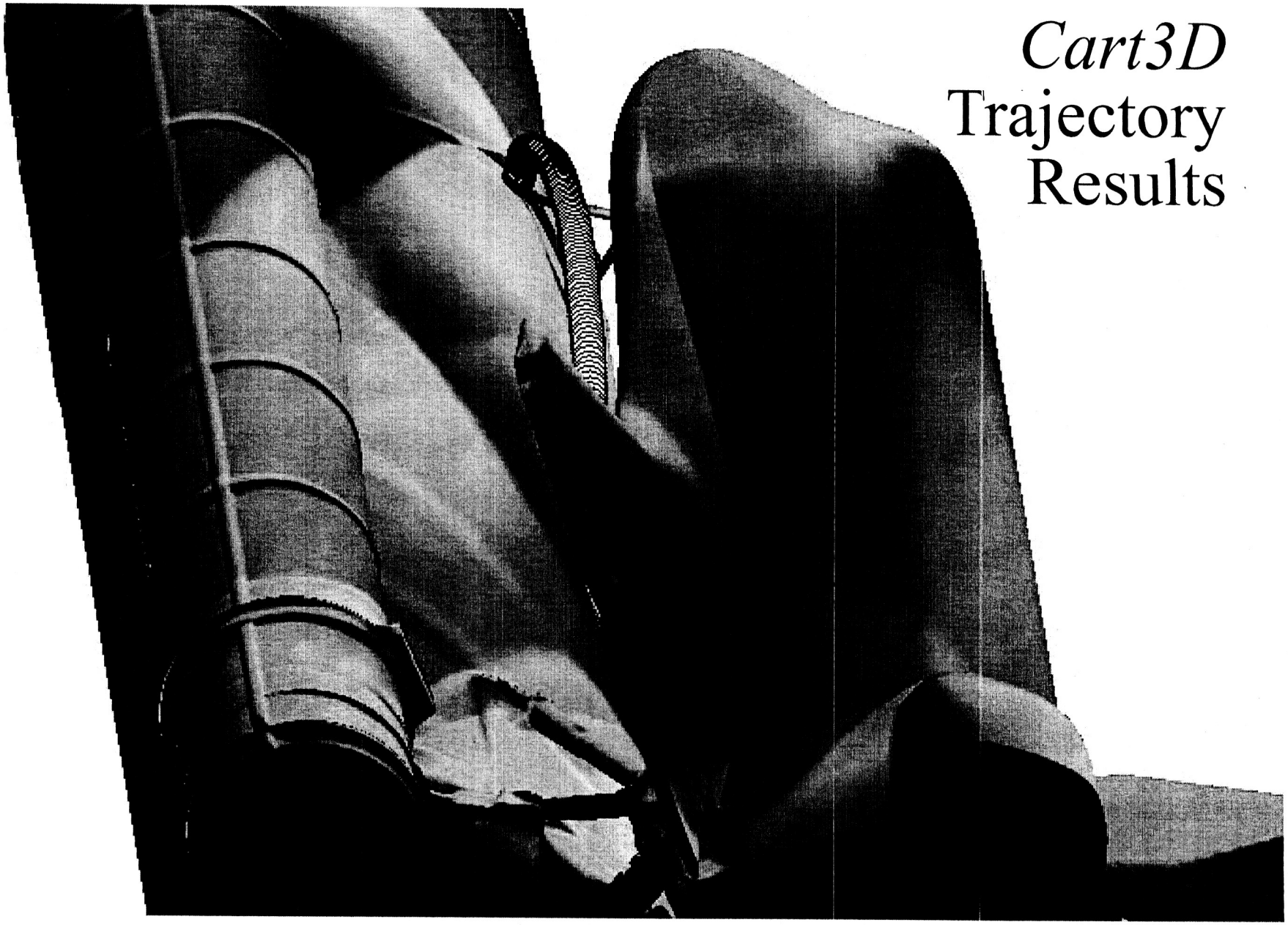
- Inviscid does well for general features - much quicker setup and simulation time (~20 mins/case on 64 CPUs)
- Lack of boundary layer at higher altitude means that viscous simulations needed for detailed bipod region loads at M_∞=2.46





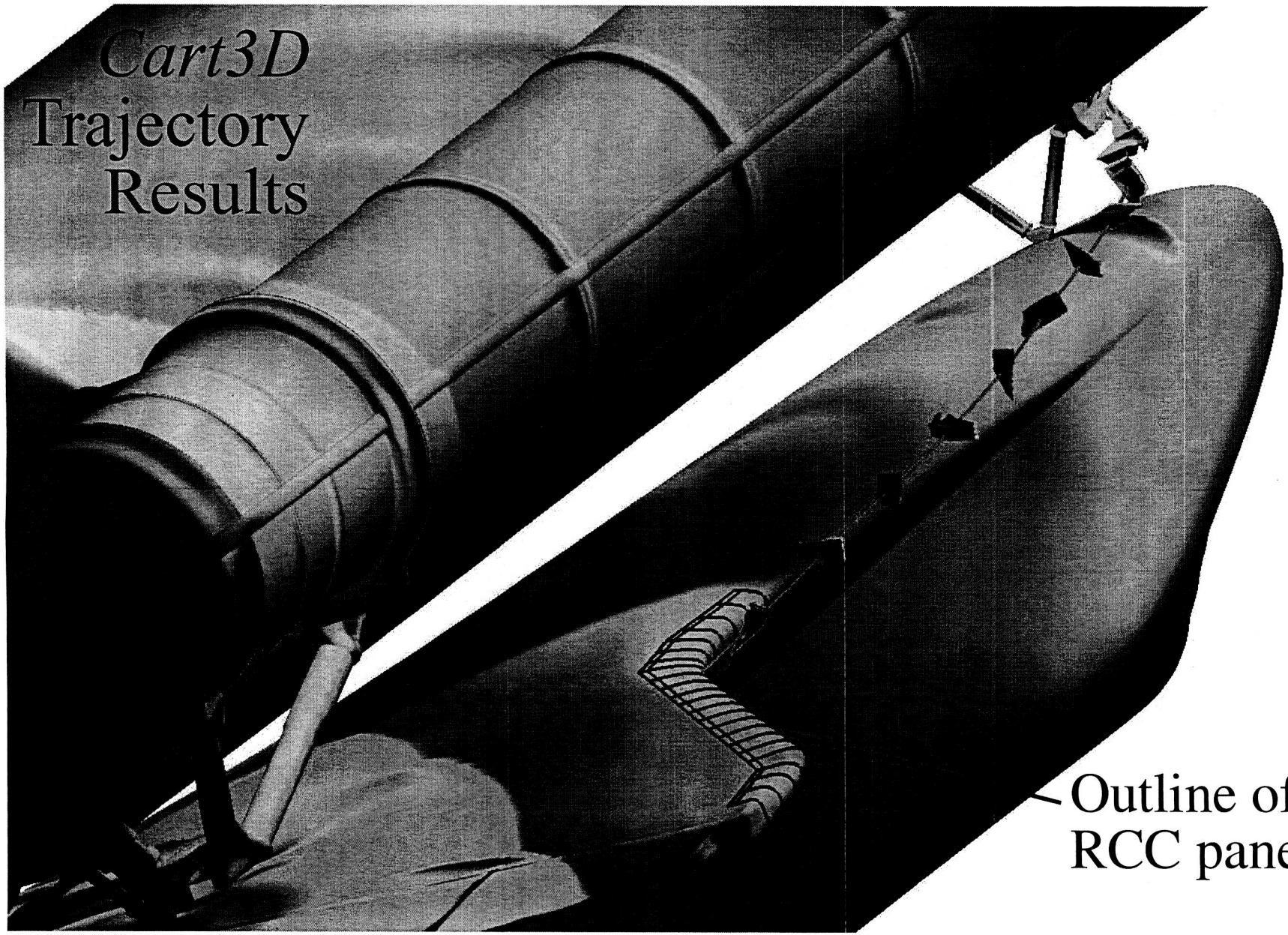
- Once debris out of viscous boundary layer, inviscid and viscous simulations should produce similar results for debris trajectory.

81.7sec MET, $M = 2.46$



Cart3D
Trajectory
Results

81.7sec MET, $M = 2.46$



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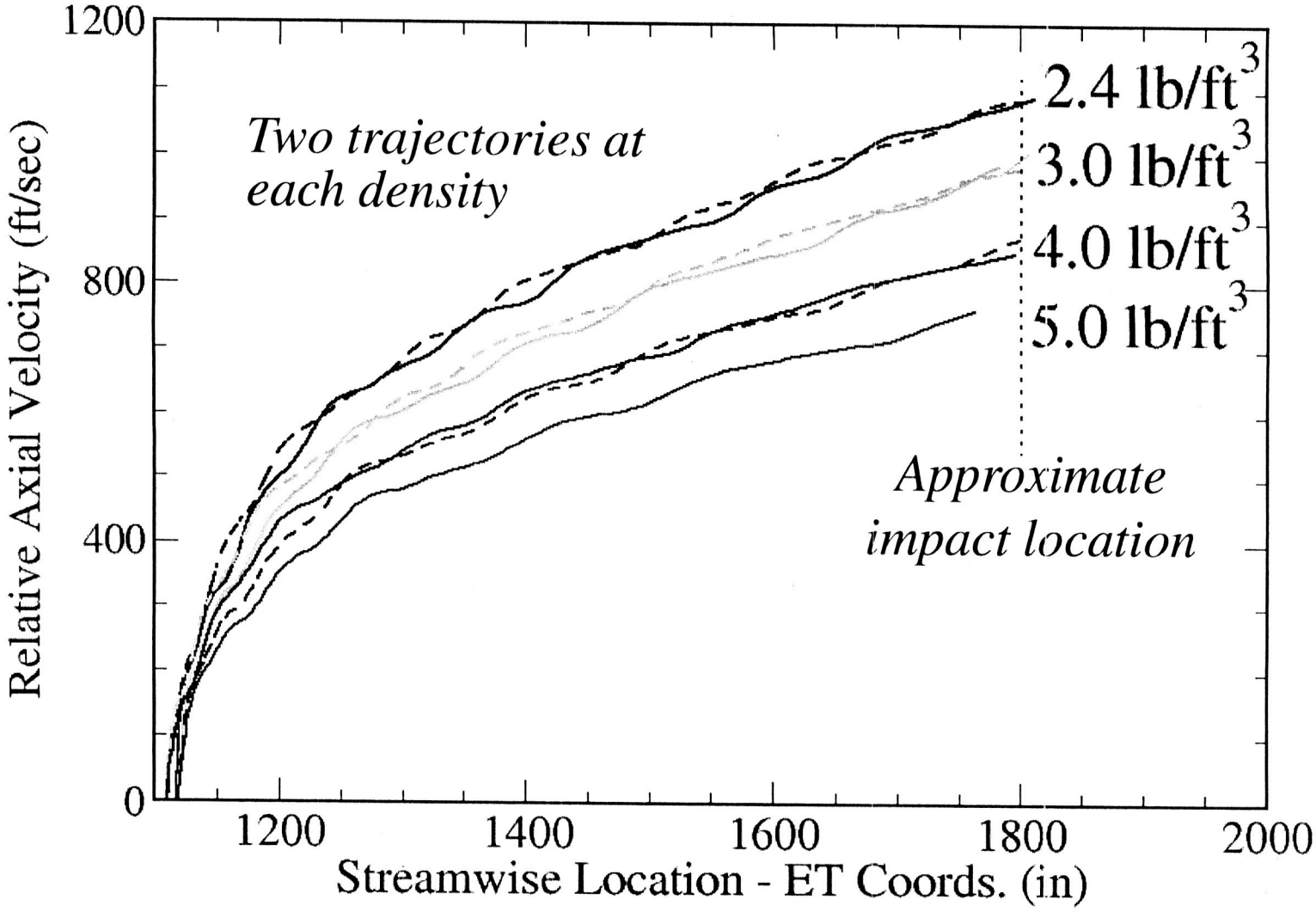
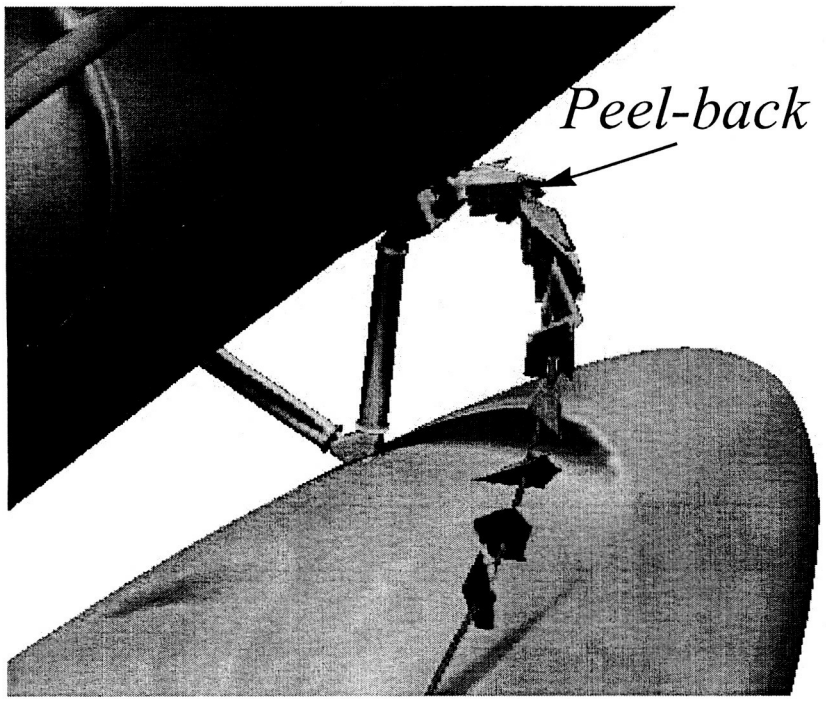
855in^3 Debris - Variation in Density

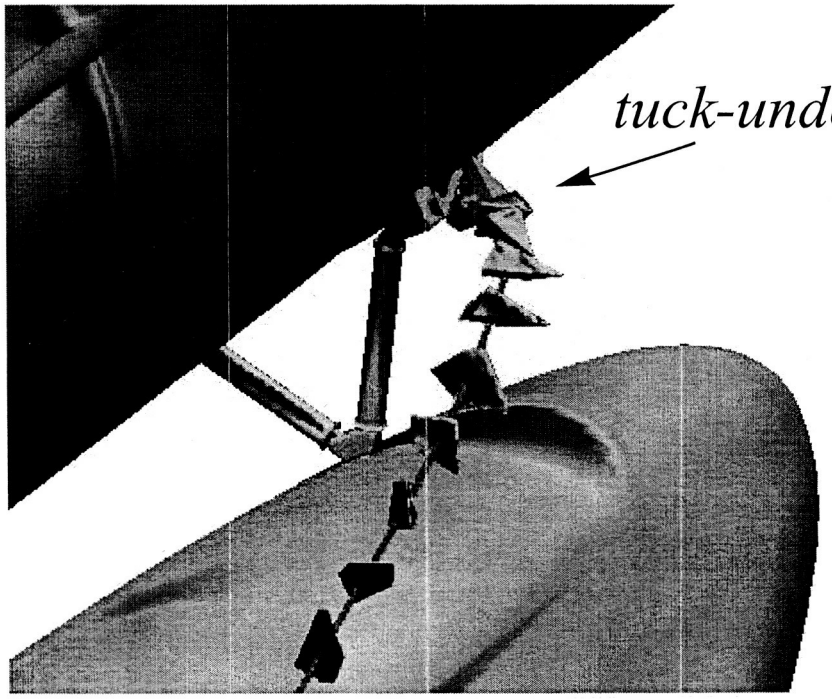


Variation in Release Conditions

Backflip

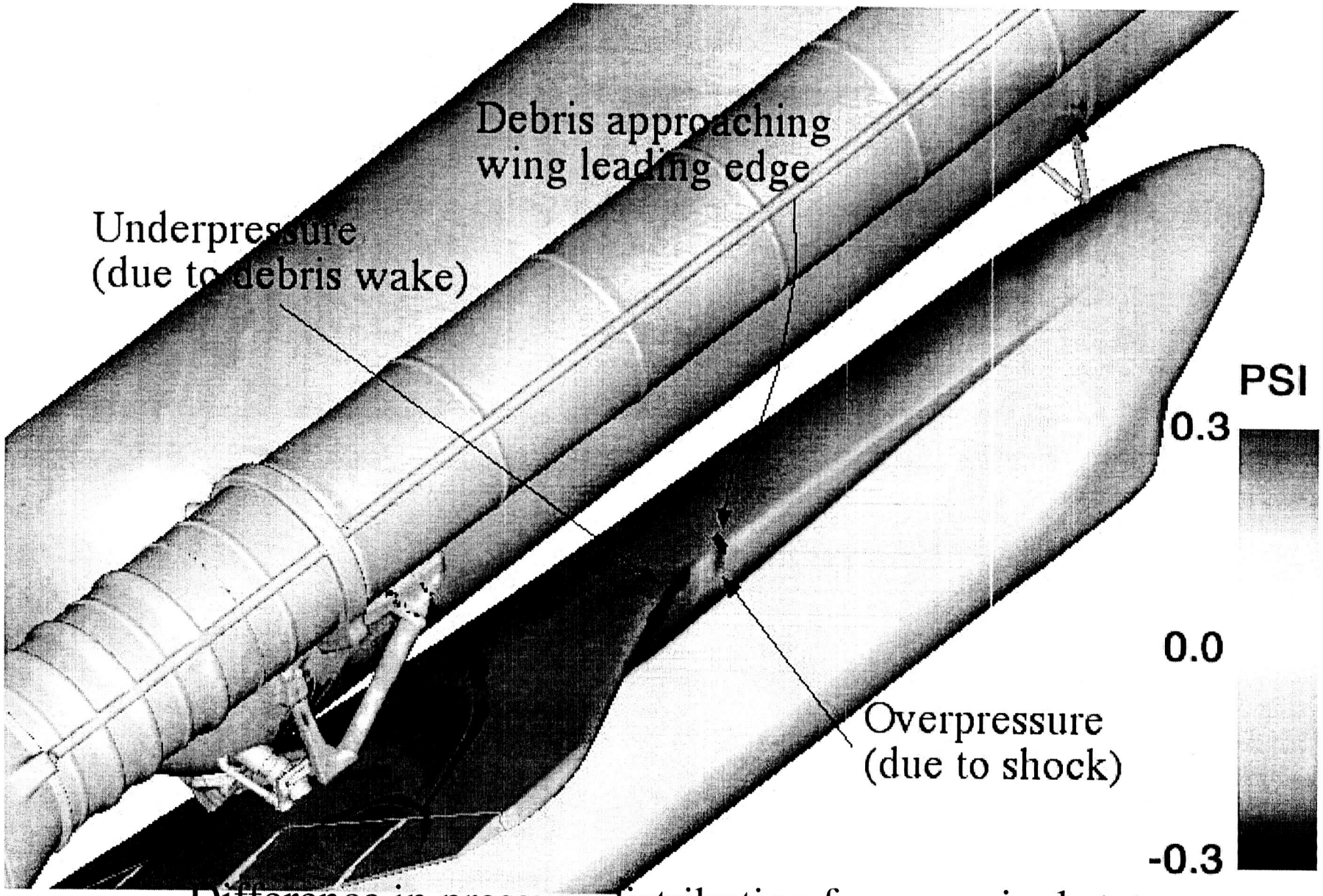


Frontflip



- Backflip release less likely to strike wing L.E. due to aerodynamic lift on first revolution
- Frontflip begins tumbling more quickly, less lift makes strike much more probable since it stays closer to vehicle.

Pressure Signature of Debris



Difference in pressure distribution from nominal state

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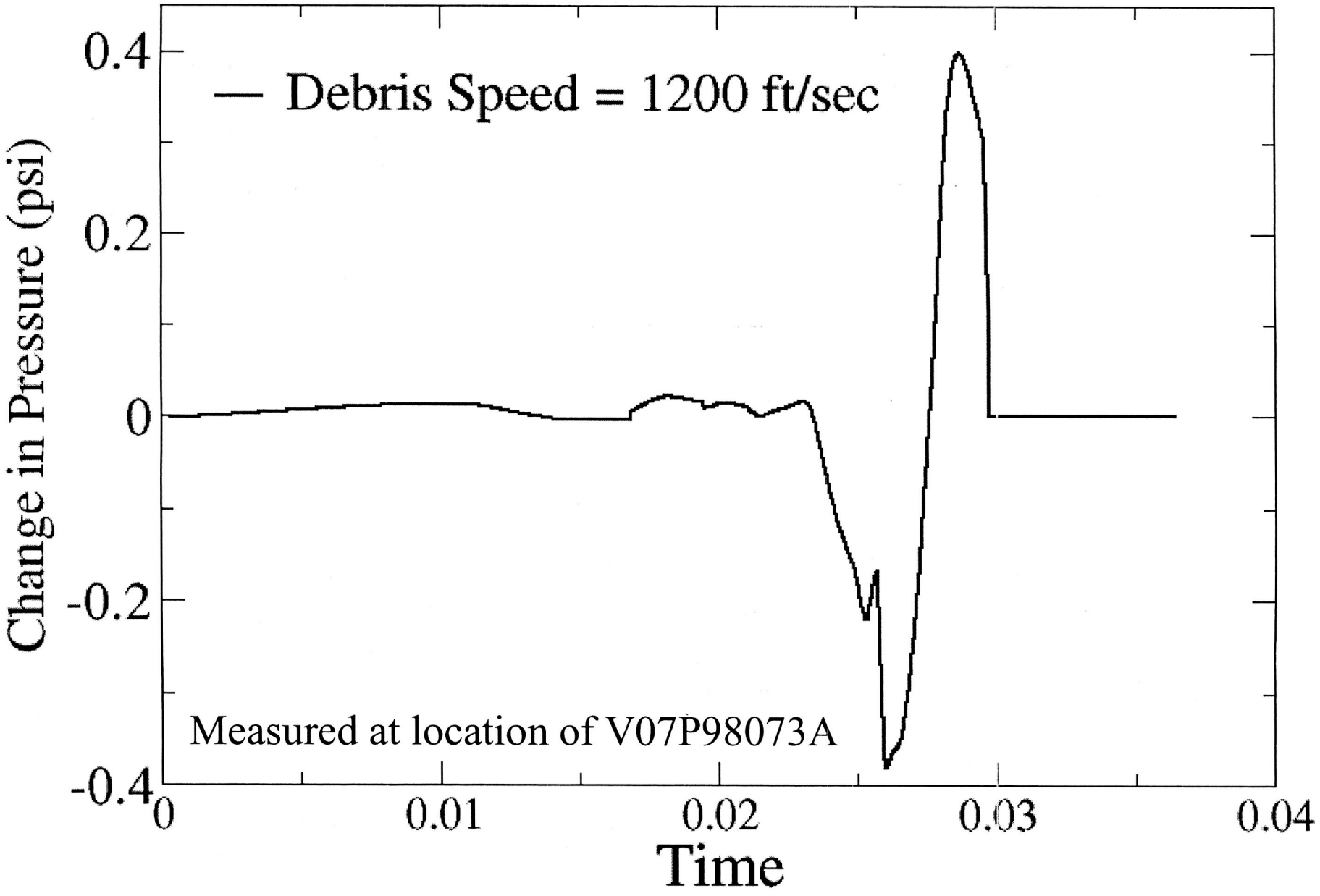
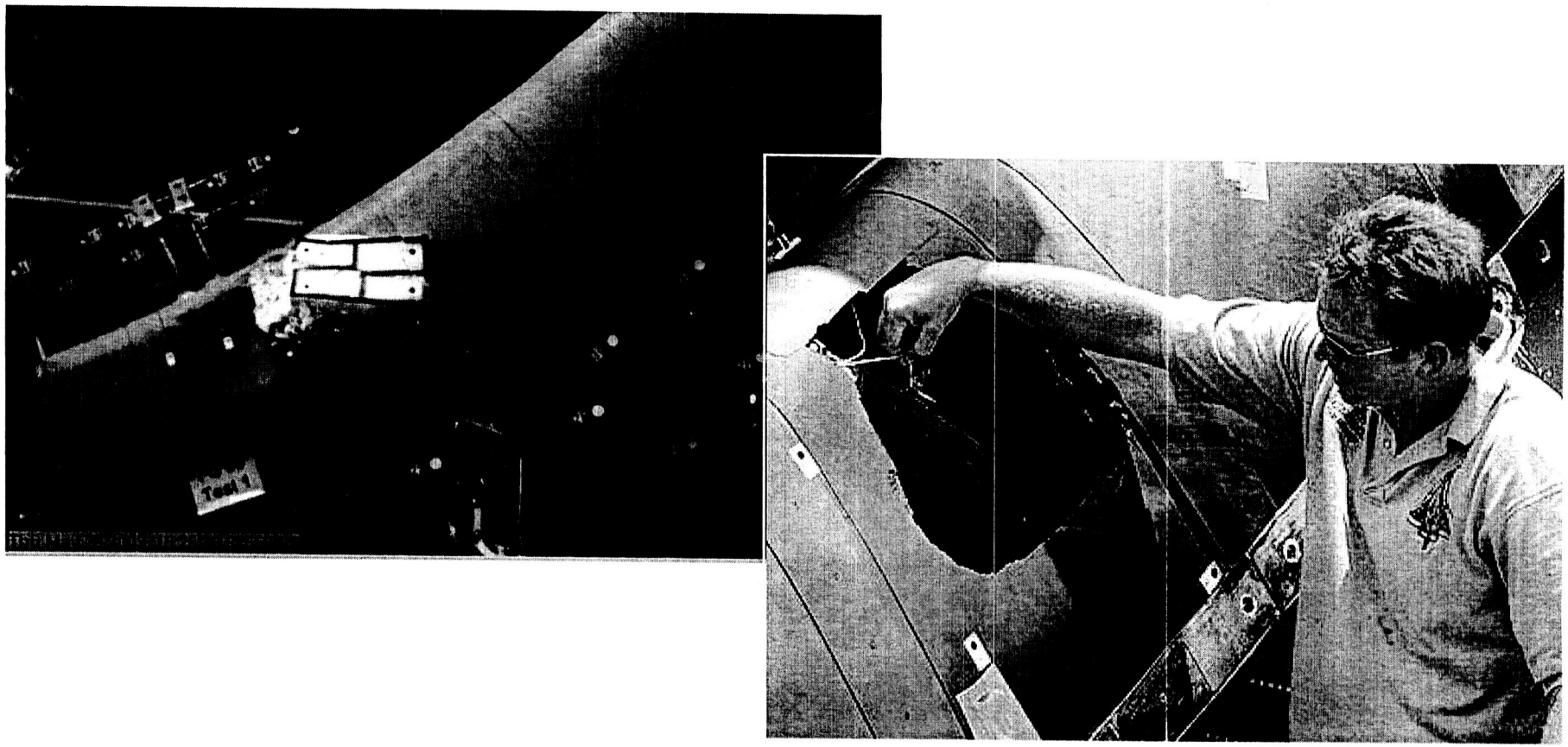
Pressure Signature of Debris



Impact on Foam Tests

- Simulation results helped to define impact velocity and foam size for testing done under CAIB (June 2003) which showed massive damage to orbiter wing RCC panels and damaged T-seals due to foam impact. Sect 3.8 of CAIB vol. 1.



Return To Flight

- Currently using Overflow simulations to quantify changes in loads due to External Tank design changes